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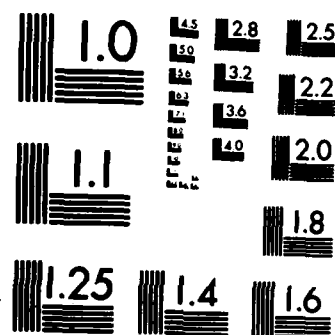
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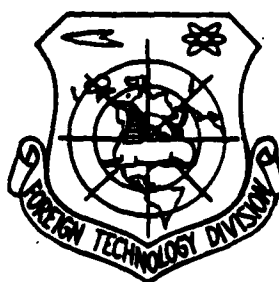
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THE RESEARCH ON SHORT BACKFIRE ANTENNA

by

L. Chang-lu, S. Xi-ming



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ABSTRACT

This paper presented a method to analyze the short backfire antenna. It interpreted the working principle of the backfire antenna relatively well. The gain of a backfire antenna developed by this analytical method was approximately 2.5dB higher than that of an ordinary short backfire antenna.

I. INTRODUCTION

Since its inception in 1965^[1], due to its advantages of high gain, symmetric main lobes, low auxiliary lobe voltage, ease of feed, simple structure, and compactness, the short backfire antenna has been adopted very rapidly in satellite communications, radar, remote control and telemetry, tracking, television, etc. Although people have used the "mirror image method"^[2-4], "leaky cavity method"^[5], "double source method"^[6], "vortex method"^[7], and "digital geometrical optics method"^[8] to analyze and interpret its high gain characteristics, yet the results were inconclusive.

In this paper, the "equivalent reflective surface method" was used to explain the working principle of the short backfire antenna. The function of the edge ring and the reason for improved gain was explained. In this paper, the "equivalent focus" of a short backfire antenna was also calculated and defined. The analysis and test showed that: under the condition that the aperture of the antenna was not increased, the gain of the backfire antenna whose feed was placed at the "focus" was approximately 2.5dB higher than that of an ordinary short backfire antenna.

II. BASIC CONCEPT

As is well known, the narrow plane wave beam radiated by a vertical reflector antenna is created by the spherical wave radiated by a feed source at the focus after being reflected by the reflective surface. The equi-phase plane on the aperture of the antenna, however, is determined by the reflecting curved surface.

We considered in approximation that the short backfire antenna to be the equivalent curved surface reflector antenna as shown in Figure 1. It also should have a "focus". In order to distinguish it from the focus of a vertical reflector antenna, we called it the "equivalent focus". The spherical wave radiated by the feed at the "equivalent focus" forms a narrow plane wave beam after being reflected by the reflecting surface. The equi-phase plane on the aperture of the antenna, however, was realized by the proper selection of the sizes and positions of the large and small reflecting surface, and the width of the edge ring.

Based on the concept described above, we will be discussing the working principle, "equivalent focus," edge ring effect, and gain of short backfire antennas in the following.

III. WORKING PRINCIPLE

We used coherence to explain the working principle of a short backfire antenna.

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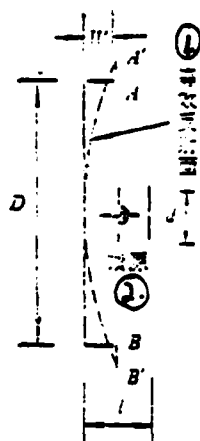


Figure 1. The equivalent reflector antenna to a short backfire antenna.

1. equivalent reflecting surface
2. feed source

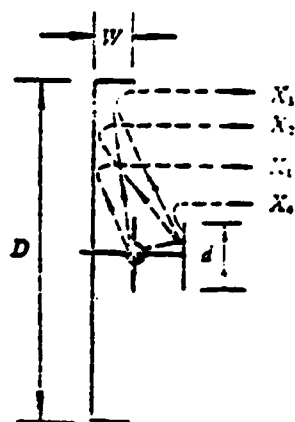


Figure 2. Schematic Diagram of the Radiation Source of a Short Backfire Antenna

As we know, the synthesized amplitude of the interference wave is related to the amplitude and initial phase of each wave series. The spatial radiation field of a short backfire antenna using half wave oscillators as the feed source can be approximately considered to be composed of the following four parts (see Figure 2), i.e.,

- X_1 - the wave radiated directly from the feed source toward the large reflector D and then toward space.
- X_2 - the wave radiated from the feed source toward the small reflector d and then radiated toward the large reflector D, and finally toward space.
- X_3 - the wave radiated toward space after being deflected by the edge ring W.
- X_4 - the diffracted wave passing through the edge of the small reflector d.

Of course, after the wave radiated by the feed source reaches the large reflector D, higher order harmonics will be formed by excitation in the cavity formed by the large and small reflectors. They will also contribute to the gain of the antenna. However, due to the fact that their amplitudes are much smaller than the four parts mentioned above, they are not taken into account here. Now let us assume:

(1)

$$X_1 = a_1 \sin(\omega t + \varphi_1),$$

(2)

$$X_2 = a_2 \sin(\omega t + \varphi_2),$$

$$X_3 = a_3 \sin(\omega t + \varphi_3),$$

(3)

$$X_4 = a_4 \sin(\omega t + \varphi_4);$$

(4)

Therefore, the synthesized wave can be written as

(5)

$$X = A \sin(\omega t + \theta).$$

By properly choosing and adjusting the diameter D of the large reflector, the diameter d of the small reflector d, the width of the edge ring W, and the distances between the feed source and the small and large reflectors so that ϕ_1 , ϕ_2 , ϕ_3 , and ϕ_4 satisfy the in-phase additive condition in the axial direction to the extent possible, then when the phase differences among them are $2n\pi$ ($n = 0, 1, 2, 3, \dots$) equation (5) becomes

$$X = (A_1 + A_2 + A_3 + A_4) \sin(\omega t + \phi') \quad (6)$$

where $\phi' = \phi_1, \phi_2, \phi_3$, or ϕ_4 .

One can see that the essence of selecting and adjusting the various geometric parameters of short backfire antennas is to make the phase of X_1, X_2, X_3 , and X_4 the same in the axial direction, or to make the phase difference $2n\pi$ (under usual conditions, when the phase difference does not exceed $2n\pi \pm 30^\circ$, it can be approximately considered to be in phase). Consequently, the amplitude of the composite wave reaches a maximum in the axial direction, i.e., the antenna gain is the highest. /333

IV. "EQUIVALENT FOCUS"

As shown in Figure 3, the radiation aperture of the short backfire antenna is S. Let us find the diffraction field at a point F on the Z axis. In order to simplify matters, let us assume that the aperture field is distributed at equal amplitude. Moreover, its value is E_0 . Therefore, according to Huygen's principle, the electric field E at point F can be calculated using the following formula

$$E = \frac{CE_0}{\lambda} \int_S \frac{e^{-iKr}}{r} dS, \quad (7)$$

where C is a constant, $K = 2\pi/\lambda$, $r = \sqrt{f^2 + R^2}$ which is the distance of each wavelet from the point F, and $dS = R d\phi dR$.

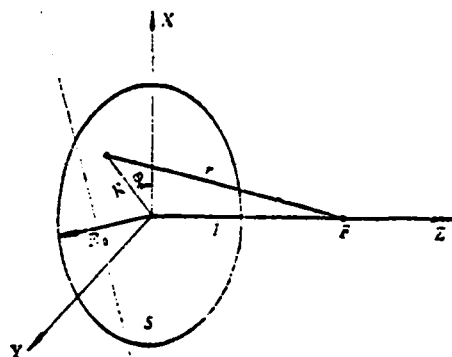


Figure 3. Geometry for calculating equivalent focus.

When the diameter of a reflector is finitely large, equation (7) becomes

$$E = \frac{CE_0}{\lambda} \int_0^{2\pi} d\varphi \int_0^{R_0} \frac{e^{-jK\sqrt{f^2+R^2}}}{\sqrt{f^2+R^2}} R dR \quad (8)$$

$$= -CE_0(e^{-jK\sqrt{f^2+R_0^2}} - e^{-jKf}).$$

The condition for equation (8) to have a maximum is

$$\left. \begin{aligned} Kf &= 2n\pi \\ K\sqrt{f^2+R_0^2} &= (2n+1)\pi \end{aligned} \right\} \quad n = 1, 2, 3, \dots \quad (9)$$

At this time, the intensity of point F is

$$E_n = 2CE_0 \quad (10)$$

We call the point F, which satisfies equation (9), the "equivalent focus" of a short backfire antenna. f is the focal length of the "equivalent focus". Hence, from equation (10) one can see that by placing the feed source at the "equivalent focus" F of the short backfire antenna which satisfies equation (9), and by adjusting the various parameters so that X_1 , X_2 , X_3 , and X_4 satisfy the in-phase condition, maximum gain can be obtained.

Substituting $K = \frac{2\pi}{\lambda}$ and $n = 1$ into equation (9), it is possible to obtain the shortest equivalent focus of a short backfire antenna as

$$\left. \begin{aligned} f &= \lambda \\ R_0 &\approx 1.12\lambda \end{aligned} \right\} \quad (11)$$

V. EXPERIMENTAL RESULTS

In order to verify the above analysis, we carried out a series of experiments.

1. The Optimum Feed Source Position. Based on the result of an analysis on equation (11), we choose that the large reflector diameter $D = 2R_0 = 2.24\lambda$, the small reflector diameter $d = 0.5\lambda$, and the edge ring width $W = 0.5\lambda$. The feed source position was varied between 0.5λ and 1.25λ . The measured pattern and gain are shown in Figures 4 and 5, respectively. From the figures one can see that when the focal length f is around 1λ , the radiation pattern is the optimum. The side lobe voltage is less than -23dB . The rear lobe voltage is below -25dB . Moreover, its gain is also the largest, and its value is 17.5dB . Its gain is approximately 2.5dB higher than that of an ordinary short backfire antenna. Figure 6 is a photograph of the antenna developed.

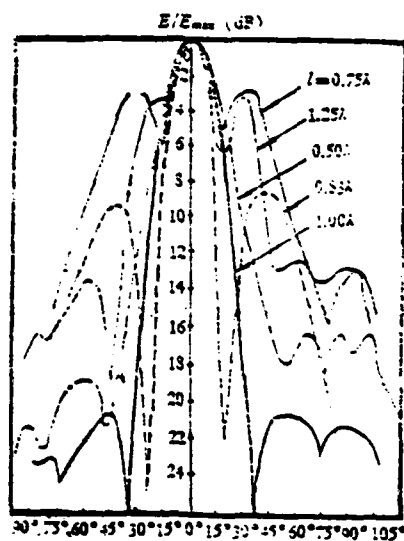


Figure 4. The effect of the position of the feed on the pattern.

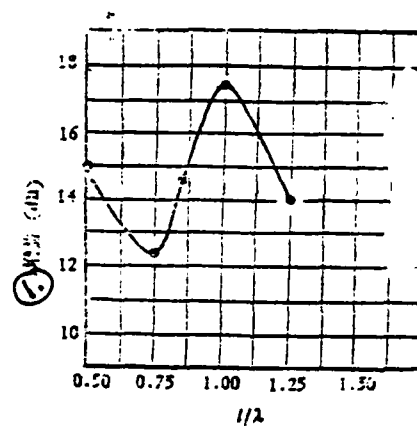


Figure 5. The effect of the position of the feed on the gain.

1. gain (dB)

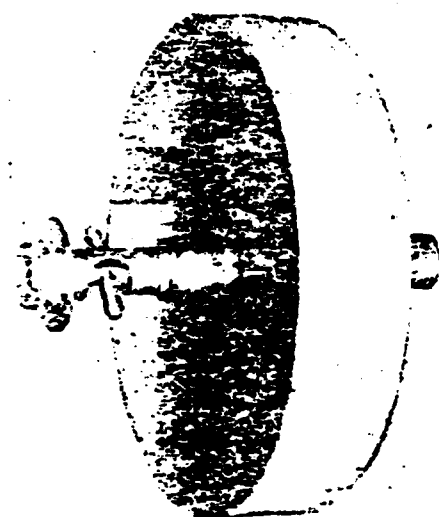


Figure 6. The photograph of the model.

2. The Optimum Edge Ring Width. As described in Section III, in the condition that the sizes of the large and small reflectors and the feed position are unchanged, by adjusting the edge ring width W , or by essentially changing the amplitude and the phase of X_3 , the composite amplitude can be maximized; i.e., the antenna gain can be optimized. Apparently the value of W which satisfies the in-phase additive condition must be the optimum edge ring width. When it is smaller or larger than this optimum dimension, the in-phase condition will be destroyed to lower the gain. In order to prove this point, the following experiment was carried out.

By maintaining $D = 2.24\lambda$, $d = 0.5\lambda$, and $l = 1\lambda$, the dimension of the edge ring was adjusted from 0 to 1λ . The measured pattern and gain are shown in Figures 7 and 8, respectively. From the figures one can see that the optimum value of W is around 0.5λ . However, because the gain of the antenna when $W = 0.5\lambda$ is only about 0.5dB higher than that when $W = 0.25\lambda$ (the edge ring width of an ordinary backfire antenna), therefore, W is better off to be 0.25λ based on a structural consideration. This is also because better electrical characteristics can be obtained. This is the reason why the optimum size of the edge ring width is not chosen for the ordinary backfire antenna. /335

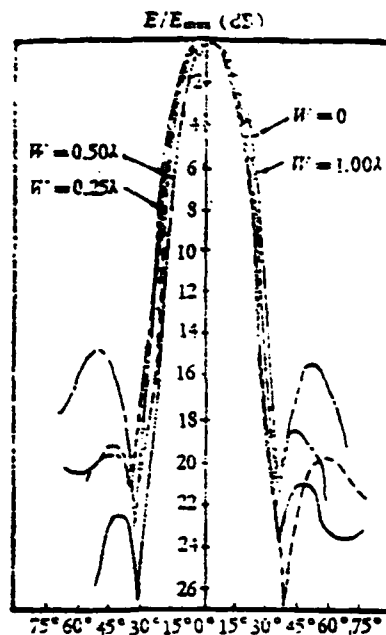


Figure 7. The effect of the edge ring on the pattern.

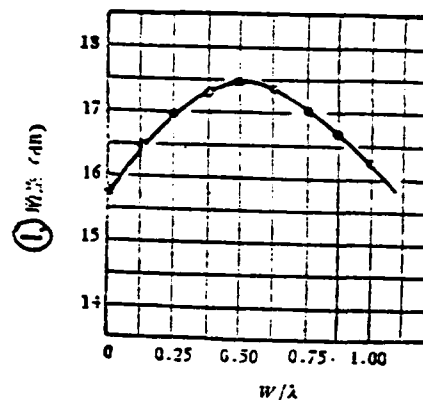


Figure 8. The effect of the width of the edge ring on the gain.

1. gain (dB)

As for the effect of edge ring width on the pattern and gain of an antenna, we can explain it in the following: Because we consider a short backfire antenna as an equivalent vertical incident reflector antenna, therefore, it is possible to use the gain formula for an ordinary aperture antenna to approximately calculate the gain of a short backfire antenna, i.e.,*

$$G = \frac{4\pi}{\lambda^2} S_A, \quad (12)$$

where S_A is the effective aperture area of the antenna. Under ordinary conditions, it is smaller than the geometrical area of the aperture S .

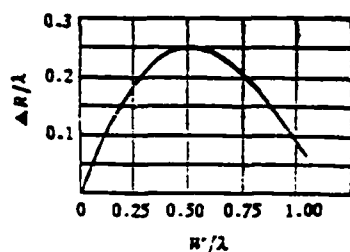


Figure 9. The effect of the width of the edge ring on the increment of the effective aperture.

As far as short backfire antennas are concerned, due to the presence of the edge ring, the effective aperture area S_A is larger than the geometrical aperture area. Let us assume that the radius of geometrical aperture is R_0 and the effective aperture radius is R_A . Their difference is called by us the "effective aperture increment", and expressed by ΔR , i.e.,

$$\Delta R = R_A - R_0. \quad (13)$$

Using Figure 8, and equations (12) and (13) we can obtain the relation between the "effective aperture increment" ΔR and the edge ring width W (See Figure 9). From Figure 9 one can see that when the edge ring width is 0.5λ , the "effective aperture increment" ΔR is the maximum. Its value is 0.25λ . The increase in

*Equation (12) is only accurate when the reflector diameter is much larger than the wavelength. For short backfire antennas with a relatively small diameter reflector, it can only be used in rough calculations.

effective aperture was also one of the reasons why the gain was further improved. /336

VI. CONCLUSIONS

1. A short backfire antenna can be approximately considered as an equivalent reflector antenna in the analysis. It also has an "equivalent focus".

2. Under the condition that the aperture size of the antenna is not increased, the gain of a short backfire antenna whose feed is placed at the "equivalent focus" is approximately 2.5dB higher than that of an ordinary short backfire antenna.

3. There is an optimum value for the edge ring width of a short backfire antenna; its magnitude is 0.5λ .

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